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MEMORANDUM FOR PRS (In-House Publication)

Propulsion Science and Advanced Concepts Division

FROM: PROI (TI) (STINFO)

30 Nov 2000

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2000-227**
Miller, T. C., "Fracture Mechanics Research at Air Force Research Laboratory"

Visit by Swedish Diplomats to AFRL
(AFRL/Edwards, 05 Dec 2000)

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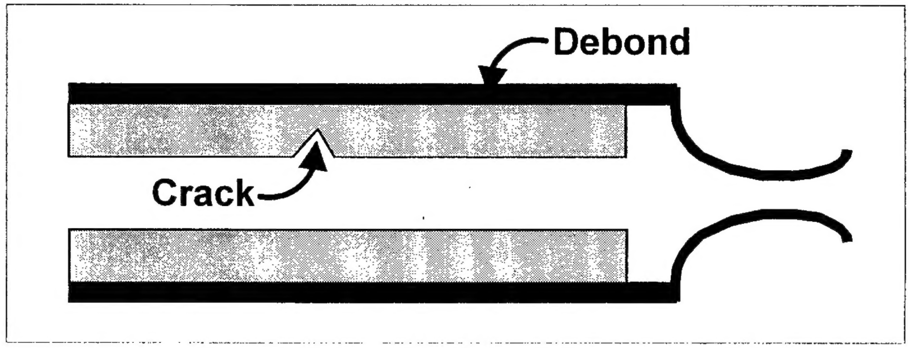
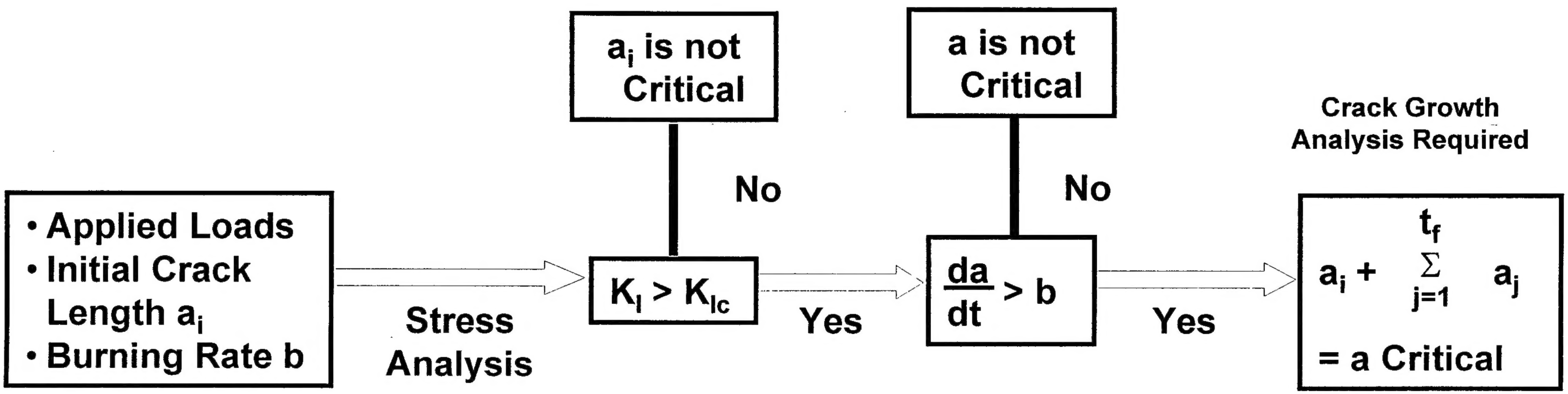
Fracture Mechanics Research at Air Force Research Laboratory

December 5, 2000

Two Crack Failure Modes in Solid Rocket Motors

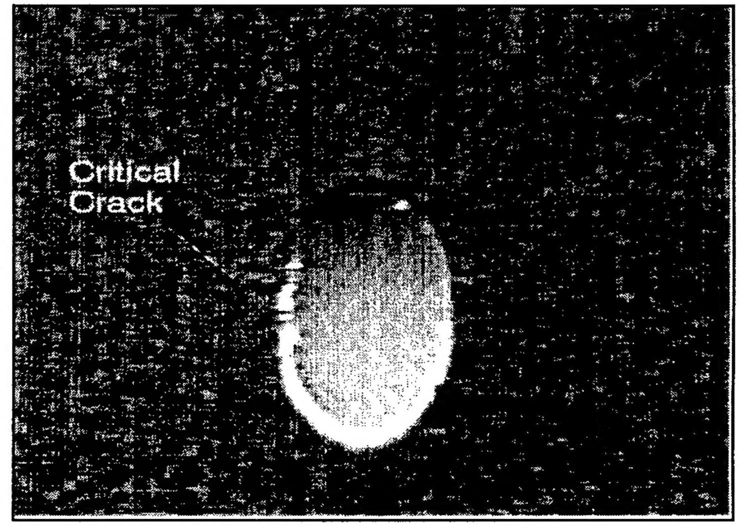


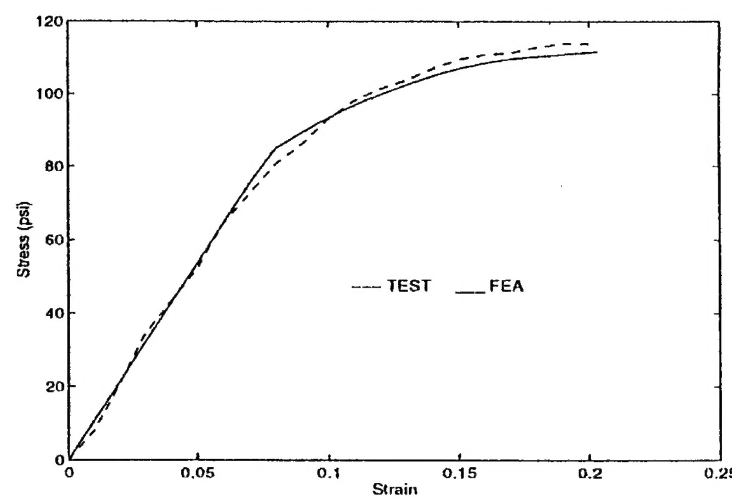
- Does Crack Propagate Under Service Loads?
- If the Crack Propagates, How Does it Propagate?



Good Correlation Exists Between the Predicted and the Measured Crack Initiation Load and the Initial Crack Length

- Based on a Micro-Macromechanical Model and a Stress Instability Criterion, the Predicted and Measured Average Initial Crack Lengths are 1.2 mm and 1.0 mm for D = 0.25 inch Hole and 1.5 mm and 1.3 mm for D = 0.5 inch Hole.

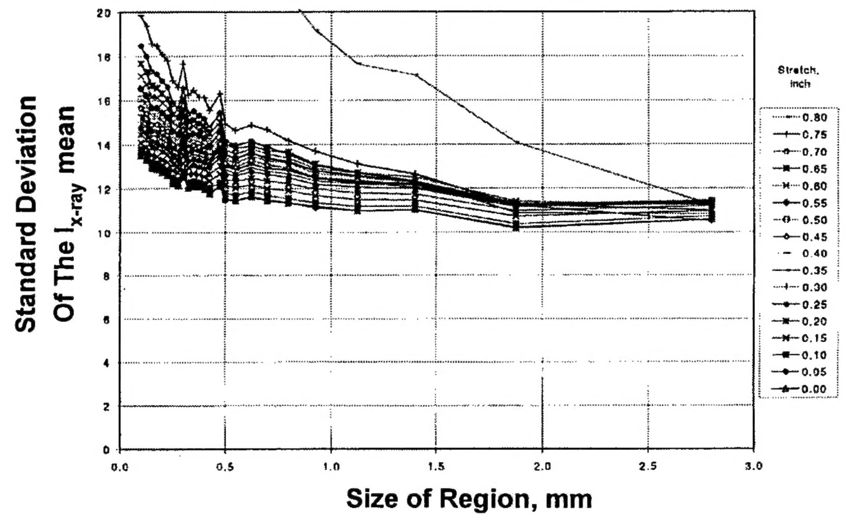


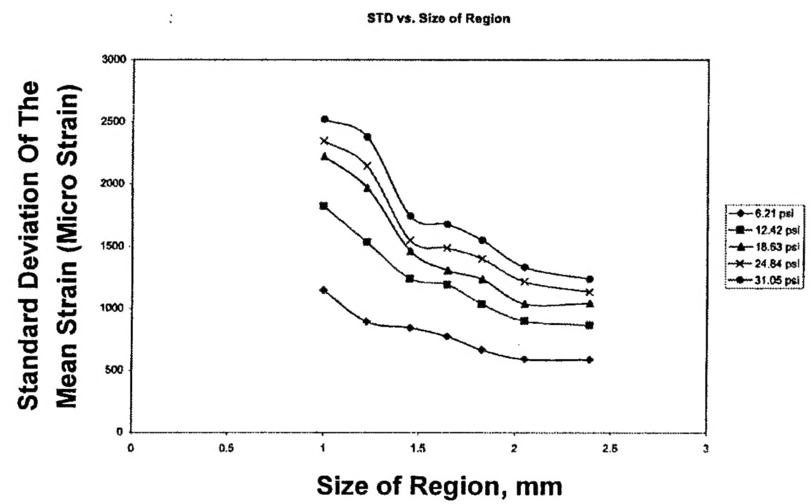


Stress-Strain Curve at Strain Rate 0.02/min

There Exists a Representative Area for a Valid Continuum Assumption of Solid Propellant

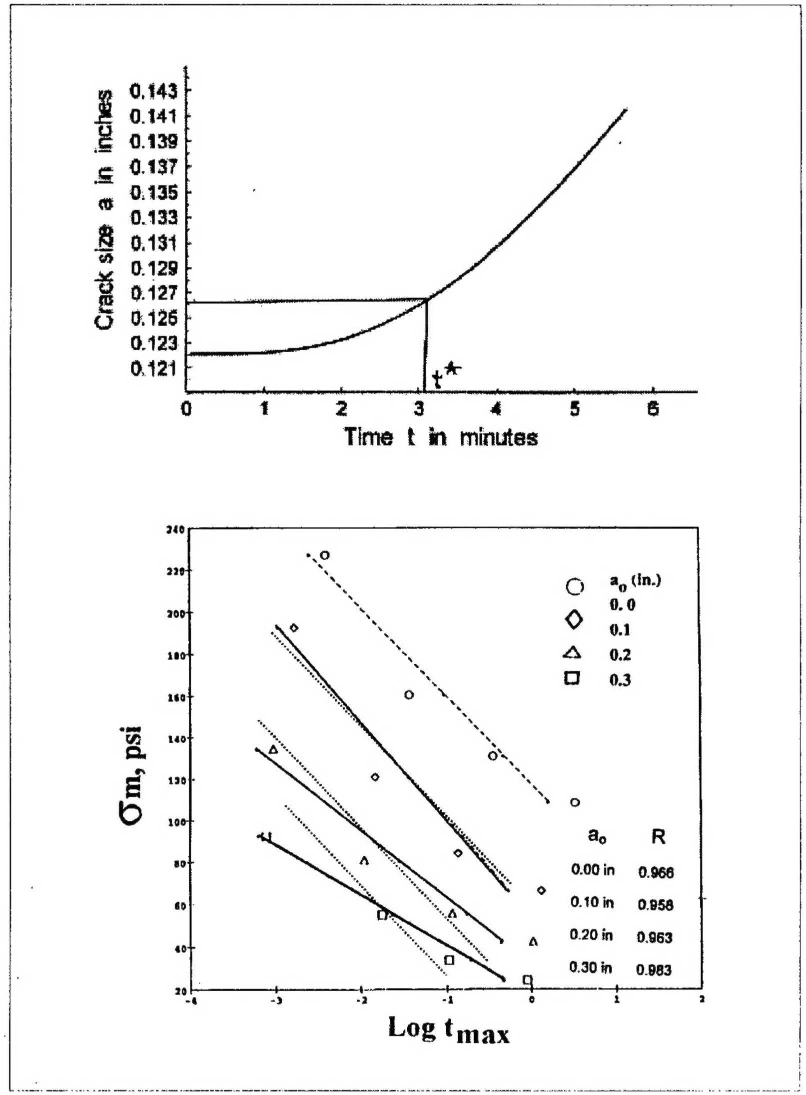
- Based on micro-measurements, the representative area is 2 mm x 2 mm.
- The existence of the representative area provides a basis for conducting stress analysis of solid rocket motors from nondestructive testing data.





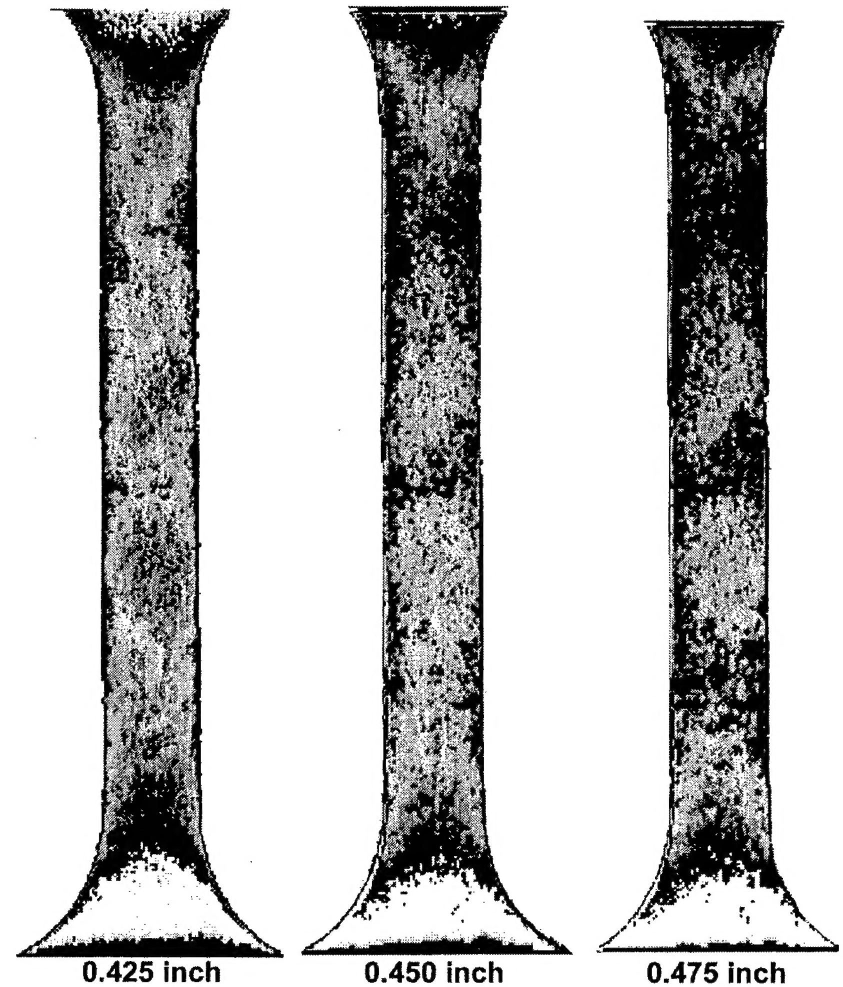
A Technique is Developed to Predict the Initial Crack Length in Solid Propellants

- Based on fracture mechanics and fracture data, the predicted and the estimated initial crack lengths are 3.3 mm and 2.5 mm, respectively.
- The initial crack size follows the second asymptotic distribution of the maximum value.
- The determination of the statistical distribution function of the initial crack makes statistical analysis of crack growth feasible.

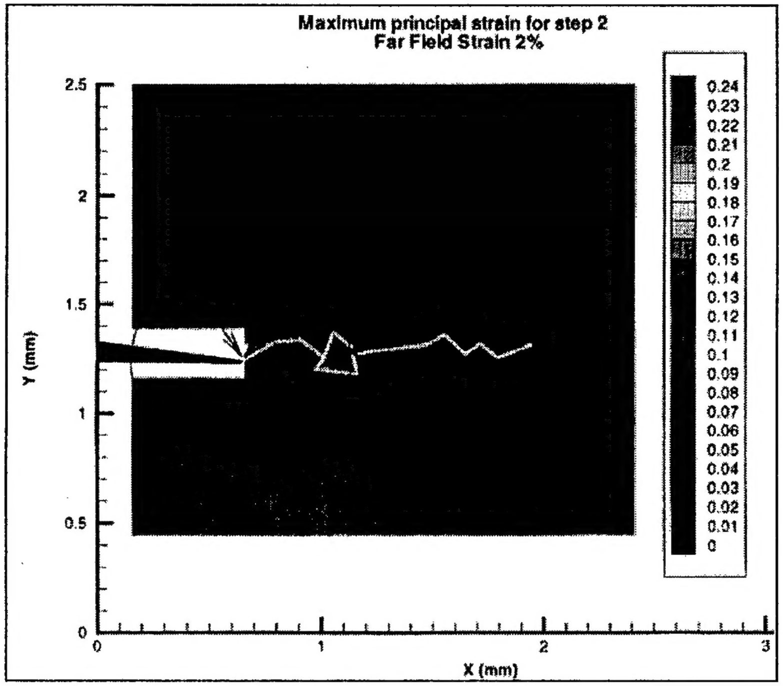


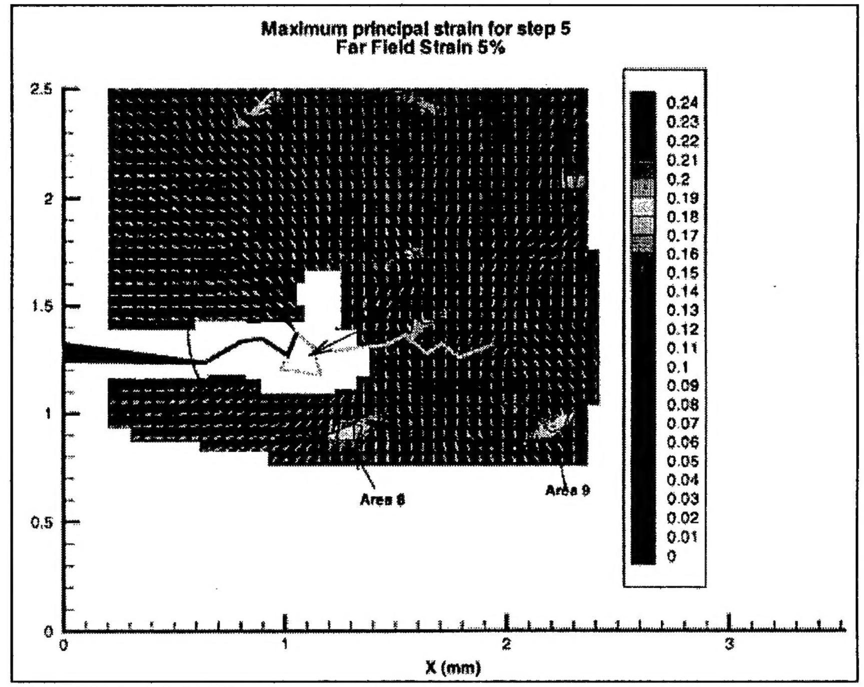
The Inhomogeneity of Microstructure Plays a Key Role in Crack Initiation and Growth

- Non-propagating cracks are formed in weak regions with a mean crack length of 1.5 mm
- In general, a critical crack is formed by the coalescence of small non-propagating cracks with an average critical crack length of 3.15 mm



Microstructure Induces a Large Inhomogeneous Variation in the Strain Field Near the Crack Tip

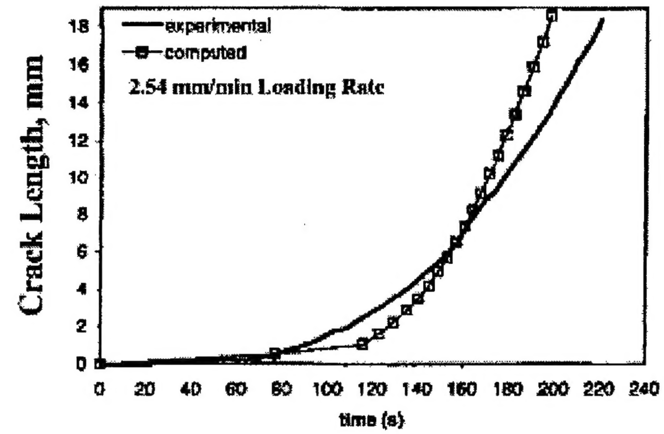


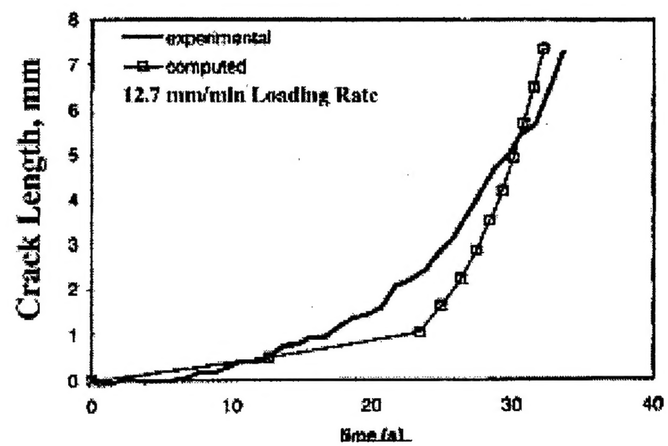


- The Interaction Between Large Deformation and Crack Propagation Process Localizes around The Crack Tip Regions

The Predicted Crack Growth Behavior Compares Well with Experimental Observation

- The variation of the strain rate near the crack tip was included in computer simulations of crack growth.
- The realistic modeling of crack growth can be a useful tool in predicting service life of solid rocket motors





Critical Defect Assessment (CDA)Program Introductory Information

Objectives:

Enhance the capabilities of the existing service life prediction methods of the Structural/Ballistic Analysis System (SBAS) in three areas:

- Fracture mechanics
- Coupled analyses between structural mechanics and Computational Fluid Dynamics (CFD) codes
- Automated geometric modeling of known flaws using non-destructive evaluation (NDE) data

CDA Task 1: Fracture Mechanics

Objectives:

Conduct exploratory development effort to enhance existing fracture mechanics models of:

- Development of the initial crack - its geometry and size (continuum failure)
- Growth initiation threshold
- Fracture growth propagation -- the direction and speed of propagation

Develop algorithms for building fracture modules into existing capabilities, such as SBAS

CDA Task 1.1: Initial Crack Development

Analytical Methods:

- Coalescence of local load-induced damage zones forms a crack
  - Continuum failure criterion will be used to determine when local material elements will fail
  - Experimental data will show the contour of the damage zone formed by coalesced failed elements
  - The coalesced damage zone represents the initial crack
  - When possible, the micromechanics model in the SLPT program will be employed

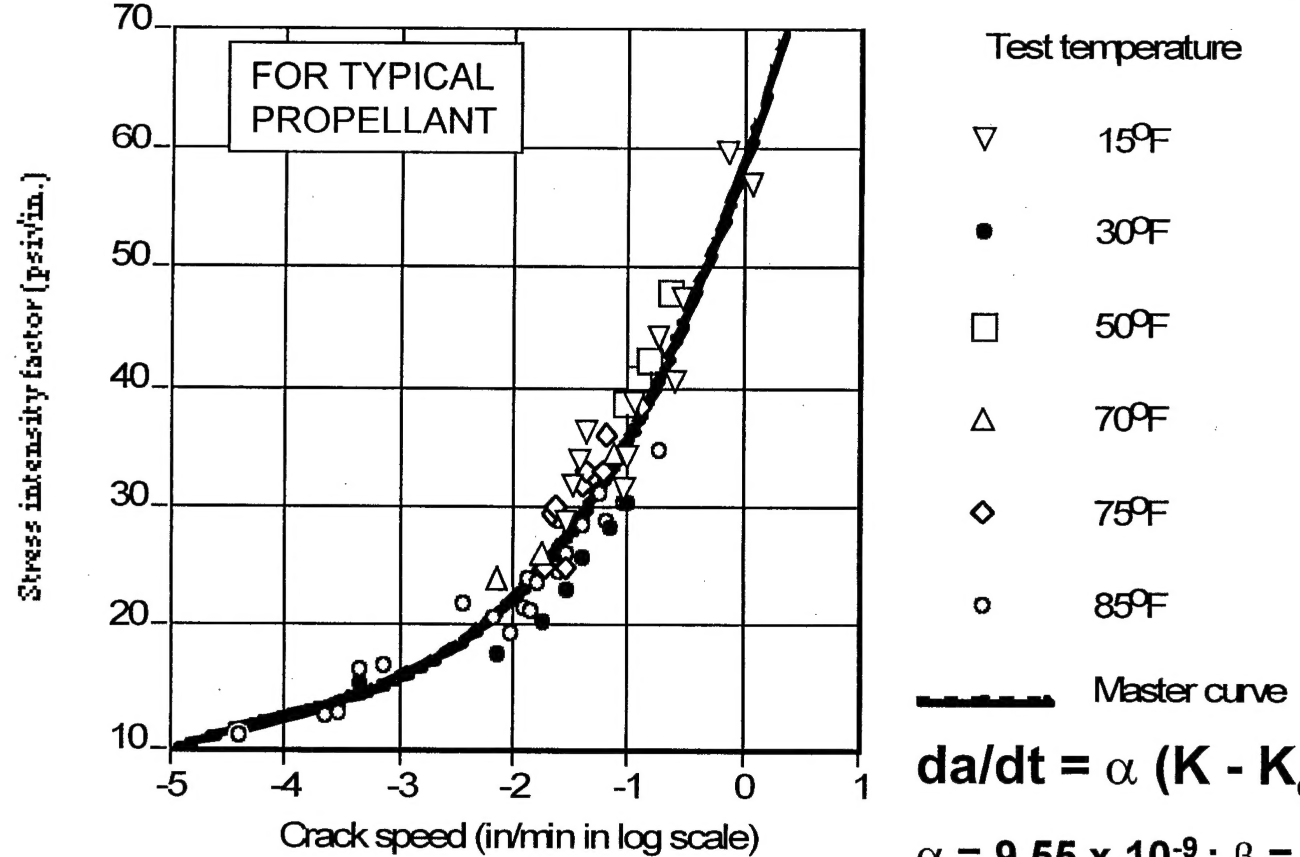
CDA Task 1.2: Crack Growth Initiation Threshold or Onset

Crack Growth Initiation Threshold or Onset

- The predictive method on this subject is reasonably developed (e.g. NASA SPIP, AF S/BRAM programs)
- The analysis method is built upon a linear elastic model. Exploratory effort on using non-linear viscoelastic (NLVE) models are also being examined
- Fracture mechanics parameters, stress intensity factor (K), strain energy release rate (G), and the J-integral, are interchangeably used
- Satisfactory predictions of crack and debond growth onsets have been made (e.g. CPIA publications)

CDA Task 1.3: Crack Growth Propagation

Characteristic Relationship Between Crack Speed and Stress Intensity Factor "K"



$$da/dt = \alpha\,(K - K_c)^{\beta}$$

$\alpha = 9.55 \times 10^{-9}$; $\beta = 4.57$; $K_c = 1.62$

low rate $\alpha = 6.07 \times 10^{-10}$; $\beta = 5.88$; $K_c = 4.79$